Using the sun
to create comfortable indoor conditions

(source: Fraunhofer ISE/Freiburg)

Content

Introduction

Human well-being and efficiency hinges decisively on ambient conditions. Key parameters in this context, alongside clean, fresh air, are the temperature and humidity of the indoor air and of the surrounding room areas. The task of air conditioning technology is therefore not only to limit indoor temperature but equally to control the humidity of indoor air. In many regions, dehumidifying the air is thus a key task of air conditioning systems.

However, all air conditioning systems – no matter what type – increase the amount of energy required, the volume of investment, and the maintenance costs for a building. The prime aim of all building planners should therefore be to minimise the requirement of air conditioning. Yet in many cases it is necessary to deploy active systems in order to control indoor temperature and air humidity. It is usually only possible to reliably control air conditioning in conference centres, theatres, department stores, multi-storey buildings, etc. with the aid of air handling units. In the past, compression chillers were mainly used to air-condition buildings. The ozone-depleting refrigerants used in these systems have been replaced in recent years with CFC-free substitutes, although these agents are also not completely without their problems for the earth's climate. What is more, compression chillers require a lot of electricity, which is primarily consumed at peak load times if no cold storage unit is used.
The peak amounts of solar radiation coincide with the demand for room air conditioning, that were higher than hardly ever before in summer. So it would seem only logical to take advantage of solar energy to power air conditioning devices. The beauty of this concept lies in the fact that cooling loads and high level solar radiation largely coincide – at least on a seasonal scale.

In view of these drawbacks, there is a growing interest in heat-driven refrigeration and dehumidifying processes. Gas-fired absorption refrigeration machines still hold major market shares, above all in the USA and Japan. These systems take advantage of free capacities in the gas grid in summer, thus reducing peak loads on the power grid. The high temperature level of gas firing allows refrigeration of up to 1.2 times the amount of heat input.

In addition, there are several different processes available that take advantage of low-temperature heat (<90°C) for refrigeration, for instance district heating, waste heat and solar heat. Alongside closed systems such as adsorption and absorption chillers, mention should also be made of open refrigeration and dehumidifying processes such as desiccant and evaporative cooling (DEC). Over the past few years, numerous systems have been built under pilot projects and demonstration projects to prove the feasibility of such systems, particularly with regard to utilising solar power. However, the only complete systems suitable for installation in buildings or building areas are central systems, as there are as yet no systems for decentralised use in single rooms.

Figure 1:
largest solar cooling site at present, Greece (site owner: SARANTIS S.A.): 2500m^2 collector area, 2x350 kW adsorption chillers (source: SOLE S.A. - design and installation)

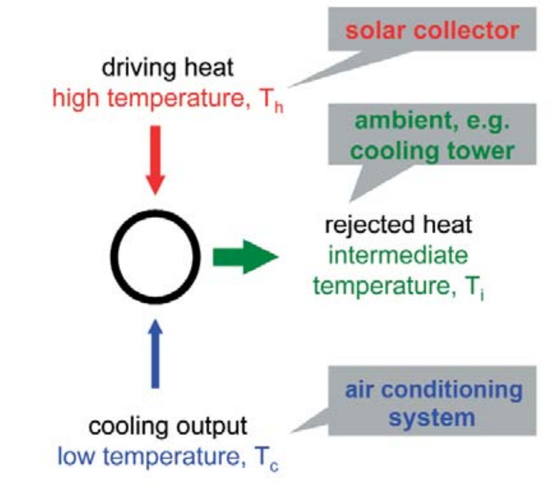
Scope of available solar assisted air conditioning methods

Different central air conditioning systems can be distinguished with regard to the various methods employed. In closed cycles, cold water is delivered by chillers, while open sorption methods are used for direct air conditioning of fresh air, i.e. fresh air is directly cooled down and dehumidified.

Cold water methods

In closed methods, chillers deliver cold water that may be used in a variety of ways for air conditioning purposes. The required temperature of the cold water hinges decisively on whether it is necessary to supply equipment that is also used for air dehumidifying (latent loads) or whether the room components connected to the system are only used to carry off sensible loads, i.e. to control temperature. In central air conditioning equipment or decentralised fan-coils that are used to control temperature and indoor air humidity, the humidity is reduced by cooling down the air below dew point, whereupon water vapour condenses and absolute humidity drops. Cold water temperatures of 6-9°C are required in order to ensure adequate dehumidifying. However, if the chiller is only used to carry off sensible loads, far higher cold water temperatures of 15-20°C are sufficient. Examples of such room components include chilled panel systems such as chilled ceilings, floor cooling systems, in-wall capillary tube mats, building component cooling and concrete core cooling or other systems of passive cooling such as air recirculation coolers working on the basis of natural air circulation.

Every thermally driven chiller is characterised by three temperature levels (see Figure 2): the high temperature level at which the driving heat is absorbed, the low temperature level at which useful cooling is delivered, i.e. the heat from the air-conditioned room is absorbed, and a mean temperature level at which the heat is rejected. In most cases, a wet cooling tower is used for heat transfer. A key figure for describing the efficiency of thermally driven chillers is the thermal COP (coefficient of performance). It is defined as the ratio of cooling output to the required driving heat input (see Figure 2).
However, a realistic comparison of different methods with regard to energy efficiency requires a consideration of the total energy expenditure including electricity consumption of pumps, etc.



$$\text{Coefficient of performance} = \text{COP} = \frac{\text{cooling output}}{\text{driving heat input}}$$

$$\text{COP}_{PE} = \frac{\text{cooling output}}{\eta_{PE,heat} \cdot \text{driving heat input} + \eta_{PE,el.} \cdot \text{electric demand}}$$

$\eta_{PE,heat}$ = efficiency of conversion (primary energy to driving heat),

$\eta_{PE,el.}$ = efficiency of conversion (primary energy to electricity)

Figure 2: Thermal driven chiller (general definition of COP, main equations) (source: Fraunhofer ISE/Freiburg)

Cold water methods

Here it must be noted that there is a direct correlation between the COP and the amount of heat transferred to the surroundings: the smaller the COP, the greater the amount of heat that needs to be transferred to the surroundings and thus the greater the expenditure of electrical energy for the cooling water circuit pump and the fan in the cooling tower; see Figure 2 for the main equations.

The main methods of providing cold water are compared in Table 1 with regard to their key factors; a detailed description with example applications follows.

method	absorption chiller			adsorption chiller
stages	single stage	double stage	single stage	single stage
sorbent	lithium bromide		water	silica gel
working fluid	water		ammonia	water
driving temperature	80°C - 110°C	140°C - 160°C	80°C - 120°C	60°C - 95°C
driven by	hot water, (steam possible, directly heated)	hot water, steam, directly heated	hot water, steam, directly heated	hot water
COP	0.6 - 0.8	0.9 - 1.2	0.3 - 0.7	0.4 - 0.7
capacity, market available	few manufacturers > 20 kW (hot water), many manufacturers> 100 kW	few manufacturers > 50 kW, several manufacturers > 100 kW	small capacity directly heated only, high capacity custom made	50 - 350 (Mayekawa), 250 - 500 (Nishyodo)
manufacturer	York ,Yazaki, EAW, Trane, Carrier, Broad, Ebara, LG Machinery, Sanyo-McQuay, Sulzer-Escher Wyss, Entropie, Century		directly heated: Robur, Colibri, Mattes; hot water, steam: Colibri, Mattes	Mayekawa, Nishyodo

Table 1:
Overview of the main methods of providing cold water with absorption and adsorption chillers for air conditioning (temperatures, COPs, market availability, range of performance, manufacturers: without warranty of completeness) (source: Fraunhofer ISE/Freiburg)

Open methods
(sorption assisted methods)

Open methods are usually based on a combination of sorptive dehumidification and evaporative cooling. They are referred to as Desiccant Cooling or Desiccant and Evaporative Cooling (DEC).

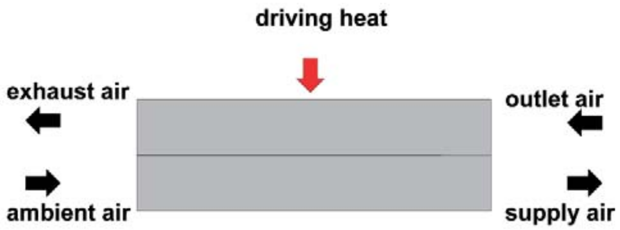
The refrigerant - water - is in direct contact with the atmosphere, which is why the process is referred to as an 'open method'. Since all systems of this kind condition air, they are always designed as ventilation systems. The prime task of a ventilation system is to deliver filtered fresh air into rooms.

Using sorptive technology it is possible to condition air, i.e. to maintain its temperature and humidity in a comfortable range, with the aid of thermal driving energy. The function of such systems thus goes beyond delivering a cooling output, which makes it difficult to compare it directly with cold water supply systems.

The definition of the COP for open air conditioning methods and the definition of refrigeration capacity and room cooling capacity are summarized in Figure 3. For these systems it is equally true that a realistic comparison regarding energy efficiency requires a consideration of all energy consumptions.

With open systems, the electrical energy powering the fans is of particular importance as a high number of additional components are usually installed compared to conventional ventilation systems, thus entailing greater loss of pressure and therefore more electricity to move the air.

The various methods are described below, including examples of applications.



$$\text{refrigeration capacity} \quad P_{cold} = \dot{V} \cdot \rho_{air} \cdot (h_{amb} - h_{supp})$$

$$\text{cooling capacity} \quad P_{cool} = \dot{V} \cdot \rho_{air} \cdot (h_{out} - h_{supp})$$

$$\text{specific enthalpy} \quad h = (c_{air} + c_{w,v} \cdot x) \cdot T_{air} + x \cdot r_0$$

$$\text{Coefficient of Performance} = \text{COP} = \frac{\text{cooling capacity}}{\text{driving heat input}}$$

V=air flow rate, ρ_L=density dry air,

c_{air}=specific heat capacity of humid air,

$c_{W,V}$=specific heat capacity of water vapour,

T_{air}=air temperature, x=absolute humidity,

r_0=specific enthalpy of evaporation

Figure 3: Definition of refrigeration capacity, capacity, cooling capacity, and COP in open methods (source: Fraunhofer ISE/Freiburg)

Systems implemented and experience (selected examples)

There are currently around 65 solar-based air conditioning systems installed in Europe, with a total collector area of roughly 17,000 m^2 and a total refrigeration capacity of approx. 5.7 MW. Most systems were built under subsidised projects and, in many cases, they were accompanied by scientific studies. The main technologies are described below, each with an example.

Absorption chillers

Absorption refrigeration is the most widely used technology for thermally driven cooling. It is mainly used in refrigeration applications based on district heat, industrial waste heat or waste heat of combined heat and power production (CHP) plants. Absorption chillers operate similarly to compressor systems, which make use of the dependence of a refrigerant's boiling and dew points on pressure.

The use of an absorbent allows thermal compression of the refrigerant to be achieved using heat as the driving energy, so that no valuable electrical energy is required for refrigeration. The most widely used refrigerant/absorbent pairs are H_2O/LiBr and NH_3/H_2O. H_2O/LiBr is commonly used for applications above approx. 4°C (building air conditioning) since it generally allows higher efficiency. The advantage of NH_3/H_2O plants is, amongst others, the lower freezing point of NH_3, which allows temperatures significantly below 0°C to be achieved.

Neither of the two working pairs have an adverse effect on the climate. The following will concentrate on the working pair H_2O/LiBr.

The evaporator is at a low pressure level (see Figure 4). The refrigerant water thus already evaporates at 4-7°C and produces useful cooling by absorbing the requisite evaporation energy. The resulting refrigerant vapour is absorbed by the concentrated LiBr solution in the absorber and – since it is now in the liquid state – can be pumped to the higher pressure level with minimum energy input using a solution pump.

By supplying solar generated driving heat at approx. 60° to 95°C, the refrigerant vapour is expelled from the H_2O/LiBr solution in the generator and condensed in the condenser by supplying cooling water at approx. 30-40°C.

The refrigerant can now again be evaporated in the evaporator. The concentrated solution in the generator is now returned to the absorber via a solution heat exchanger where it absorbs refrigerant again.

The efficiency of the plant is increased significantly by cooling the concentrated solution and preheating the diluted solution in the working fluid heat exchanger. This results in typical COP values of 0.6 to 0.8 for single-stage systems. Double-stage systems reach higher COP values up to 1.2, but also require driving heat at higher temperature levels, around 140-160°C.

Applications have so far concentrated on absorption chillers with refrigerating capacities of more than 200-300 kW. A machine with a nominal capacity of 35 kW and a minimum driving temperature of 75°C from a Japanese manufacturer has for long time been the only system on the market for the small capacity range. However, recently several companies have started to provide small heat driven water chillers in the range of 20 kW and below.

The requirement of good part load efficiency (high COP values) at low, variable driving temperatures have resulted in the development of advanced absorption chillers for solar-assisted refrigeration.

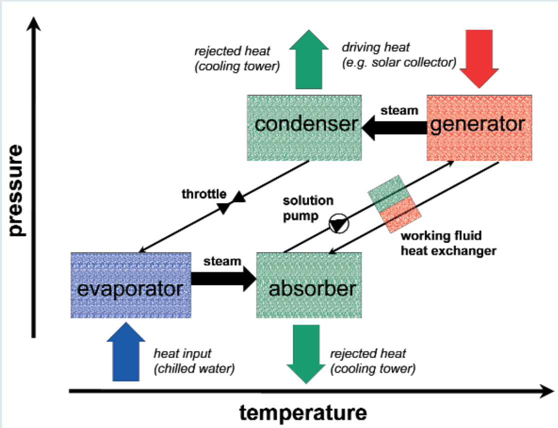


Figure 4: Principle of an absorption chiller (source: Fraunhofer ISE/Freiburg)

System with absorption chiller:
Office Building in Guadeloupe

The office building has been built in Guadeloupe, at Basse Terreand and is in operation since 2003. This Building, of high environmental quality, includes a solar assisted cooling system employing an absorption chiller.

Figure 5 shows the layout of the system. Cooling power is distributed by means of a chilled-water circuit and is produced according to the following principle:

- Pre-cooling of the chilled water circuit (nominal temperatures: 7 - 12°C) by an absorption chiller (30 kW), driven by vacuum tube solar collectors, and connected to a water-based open cooling tower.

- The back-up cooling energy is supplied by a vapour compression chiller (liquid based cooling plant with 55 kW capacity), with air cooling of the condenser. Without the absorption machine, this plant would have required a power input of 90 kW.

The heat supply for the absorption chiller is required in a temperature range of 85 - 95°C. This dictated the choice of vacuum tube collectors from the beginning of the project.

The system is not equipped with a full-size hot-water storage tank. Instead, the collectors are connected to the generator of the absorption chiller by a small buffer tank (< 100 litres). The cooling output (30 kW) was established so that it would always be slightly less than the load at all times during sunny periods. In this way, the absorption chiller can operate directly with the sun, and use all the energy supplied by the solar collectors for cooling. When the load is higher, the conventional chiller makes up the difference.

This system is expected to save a third of the electricity billed for air-conditioning every year, if compared to a conventional compression system, which would have a size of 90 kW: illustrates both the cost distribution and the initial cost breakdown for this solar-assisted cooling system. An additional cost of 18.000 ⇔ for system design should be added for the part concerning the solar cooling equipment. The solar collectors represent more than 40 % to the overall cost.

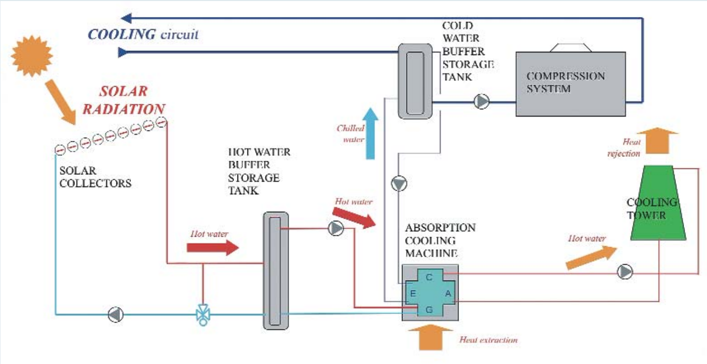
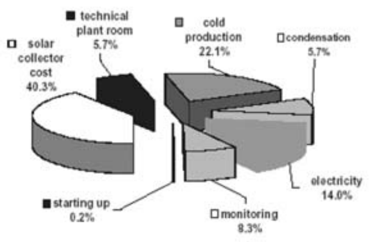


Figure 5: Plan of the solar assisted cooling system employing an absorption chiller at the office building in Guadeloupe. (source: Tecsol)



component	cost, €
solar collector cost	39 365.00
technical plant room	5 616.00
cold production	21 614.00
condensation	9 224.00
electricity	13 644.00
monitoring	8 093.00
starting up	203.00
total	97 759.00
specific cost, € per kW cooling power	2 794.00
Collector specific cost, € per m²	635.00

Figure 6: Cost distribution and the initial cost breakdown for the entire system. (source: Tecsol)

Adsorption chillers

Adsorption chillers have until now only been commercially available from a few manufacturers in Asia. The main area of application is identical to that of absorption systems. Adsorption is the reversible bonding of gas molecules in the pores of a highly porous adsorbent such as silica gel.

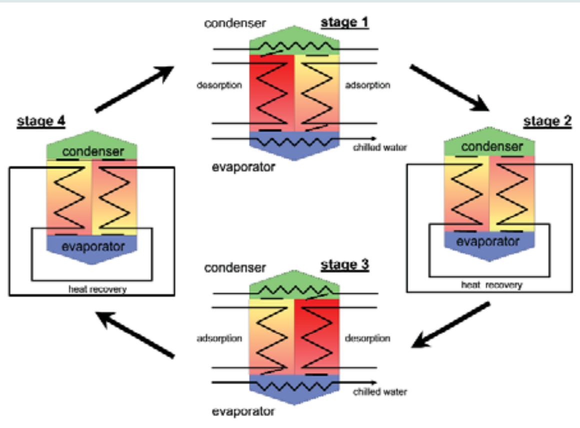
In adsorption chillers, the refrigerant vapour built up in the evaporator is bonded to these adsorbents. Therefore, in order to ensure smooth, uninterrupted operation, this requires at least two separate chambers with adsorbents - in addition to the evaporator and the condenser. Each of the identical chambers contains sorbent material stored in a heat exchanger.
While one chamber adsorbs the refrigerant vapour built up in the evaporator and thus maintains the refrigeration process, the other chamber is regenerated by passing a heat transfer medium, e.g. water heated by a solar unit, through it. The refrigerant vapour is expelled and condenses in the condenser. A cooling circuit is required to cool the condenser and also to remove the adsorption heat released during adsorption. After a certain time, adsorption comes to a standstill and the task of the chambers switches, with a short interval for heat recovery.

Figure 7 shows a complete cycle; Figure 8 shows the resulting temperature curve. So far, adsorption chillers are only manufactured by two Japanese firms.

These devices are both larger and heavier as well as more expensive than comparable single-stage absorption chillers. However, adsorption technology does have several important features that make it interesting for thermally driven refrigeration.

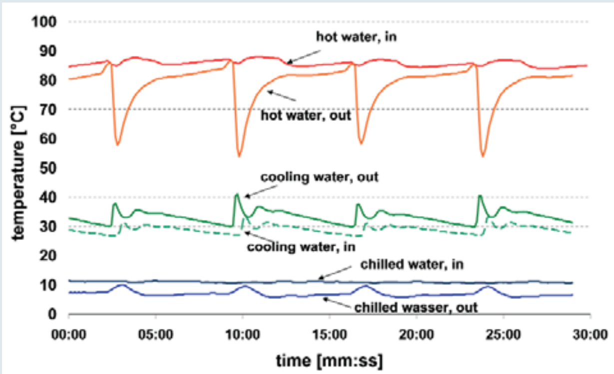
For one, no moving parts are required in the vacuum section. What is more, there is no possibility of crystallisation as is the case in absorption systems, with the effect that there are no limitations on cooling water temperature.

Improvements in the design of heat exchangers, new materials and new processes in container technology promise far higher power density levels, both in terms of mass and volume.



(source: Fraunhofer ISE/Freiburg)

Figure 7: Operating cycle of an adsorption chiller



(source: Fraunhofer ISE/Freiburg)

Figure 8: Temperature curve (hot water, cold water, cooling water) of an adsorption chiller.

System with adsorption chiller:
University Hospital Freiburg

In 1999, a solar-based air conditioning system for a lab building at the University Hospital in Freiburg, Germany, was installed. The system, which operates with an adsorption chiller, cools water in the cooling circuit from 14°C to 10°C, thus supplying the air coolers in two ventilation systems.

The solar collector array consists of 170 m² (aperture area) of direct-contact vacuum tube collectors arranged in two main arrays. One of the arrays (90 m²) is inclined 45° south, the other array (80 m²) 30°. In the case of insufficient solar heat, a steam fired heat exchanger can be activated as a secondary heat source.

Continuous adaptations and improvements, both in the hydraulic layout and the control system, were implemented during the project.

Figure 9:
Adsorption chiller at the University Hospital of Freiburg (source: Fraunhofer ISE/Freiburg)

The main modifications, which may be seen as general planning guidelines, were:

- Integration of a serial buffer in the return flow of the chiller is important in order to ensure stable operation. This is due to the periodical activation of the adsorbers and the resultant temperature fluctuations (see Figure 8).

- The buffer may only be charged by surplus solar heat and not by the chiller's return flow if operating with vapour.

- Load-dependent control of driving temperature, starting at a low level, increases the percentage of solar coverage; in the event of inadequate refrigeration, the driving temperature is increased.

- Part load behaviour can be substantially improved by operating with a variable period length. This is a modification over the control as set by the manufacturer.

In the course of continuous work on the system, it was possible to substantially improve performance. The chiller now achieves COP values that conform to manufacturer specifications.

System with adsorption chiller:
University Hospital Freiburg

heat supply	type of collector	evacuated tube collector (direct contact)
	collector area	153 m^2 (absorber), 230 m^2 (cross area)
	hot water storage	6 m^3 parallel installed, 2 m^3 installed serially to the hot water return of the chiller
	back up heating source	steam
cold supply	type of chiller	adsorption chiller NAK 20/70 (Nishyodo/Japan)
	capacity	70 kW
	back up chiller	-

Table 2:
Key figures of the installation at the University Hospital of Freiburg. (source: Fraunhofer ISE/Freiburg)

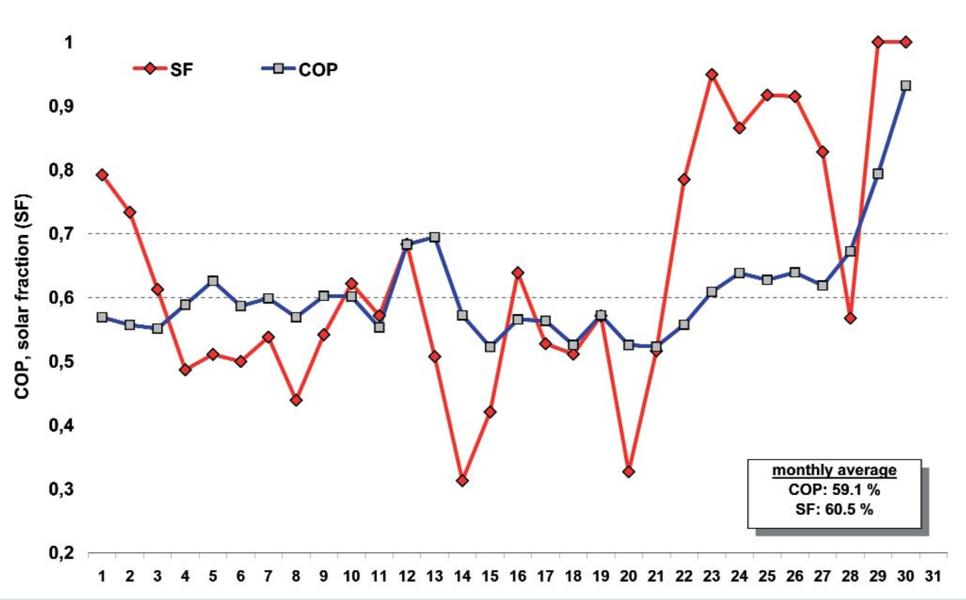


Figure 10:
COP and solar fraction of the system at the University Hospital of Freiburg (summer 2003) (source: Fraunhofer ISE/Freiburg)

Processes with sorption rotors

The most common open process today uses sorption rotors. These are rotors in which the sorbent material - silica gel or lithium chloride - is bonded with a matrix base and through which air can flow. A part of the sorption rotor alternately passes through the fresh air side, on which the outside air is dehumidified, and another part passes through the return air side, on which the water is desorbed from the sorption material with the aid of hot air.

The most common layout and sequence of states in the T-x-diagram of humid air are depicted in Figure 11. The COP (see Figure 3: Definition of refrigeration capacity, cooling capacity, and COP in open methods for a definition) depends considerably on outside air conditions. Typical values of COP and refrigeration output are shown in Figure 12.

It must be noted that it is possible to achieve very high COP values in moderate outside air conditions. The reason is that in the borderline cases with low outside air temperature and humidity, the process becomes a purely 'passive' process that takes advantage solely of evaporation cooling, i.e. does not require sorptive dehumidification and thus no thermal driving heat. Other variations are possible in addition to the layout depicted below.

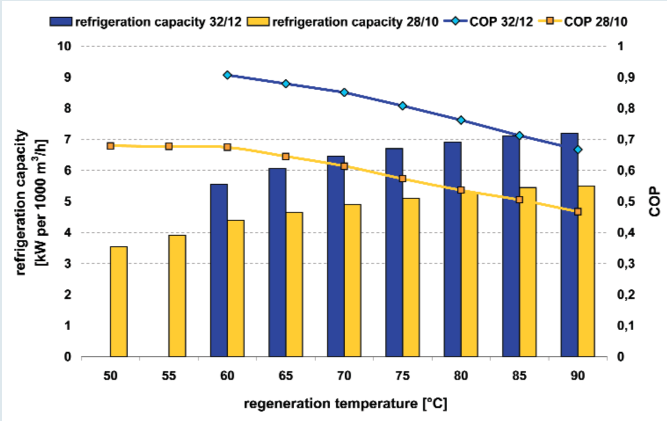


Figure 12: COP and refrigeration output of the standard process for different outside air conditions (source: Fraunhofer ISE/Freiburg)

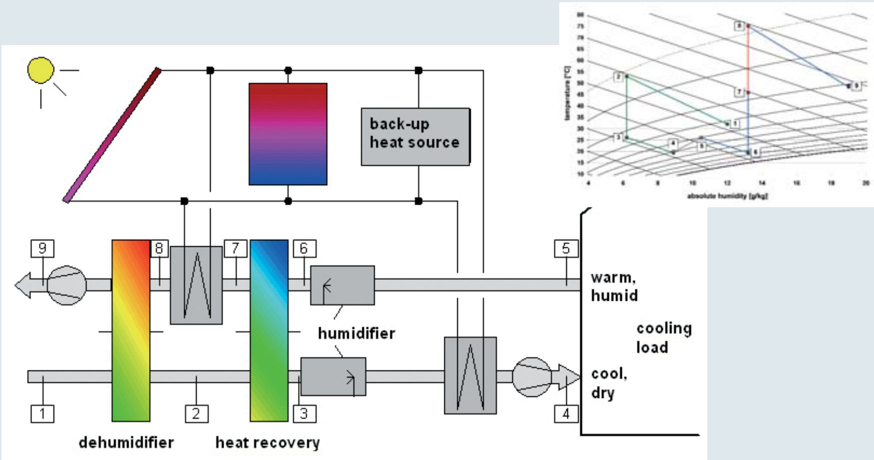


Figure 11: Standard processes of desiccant air conditioning with sorption rotor and corresponding air states in the T-x-diagram of humid air (source: Fraunhofer ISE/Freiburg)

System with sorption rotor:
Pompeu Fabra Library in Mataró

The system built and implemented in the public library Mataró /Spain is a dessicant cooling system with air as the only heating and cooling fluid. The unit is coupled to a PV-solar air heating system.

The system is working according to main seasons based on the following principles:

- Summer – desiccant cooling system with thermal solar energy used to regenerate the system (by heating for releasing humidity);

- Winter – using a heat recovery wheel, thermal solar energy is indirectly used for heating.

- The system also incorporates auxiliary coils for cooling and heating, respectively, which will cover the heat needs when solar energy is not sufficiently available or there are exceptional critical loading conditions.

From monitoring performed during the 2002 summer period at the new solar air conditioning system at Pompeu Fabra library in Mataró, the following conclusions have been obtained:

- Water consumption is high so it would be necessary to introduce any system for water recycling and the regulation of humidifiers could be optimised.

- The performance of the air treatment unit, the solar system and the regulation and control system are as predicted on design period.

Figure 13: DCS unit mounted on the roof at Mataró Library (source: FH Stuttgart)

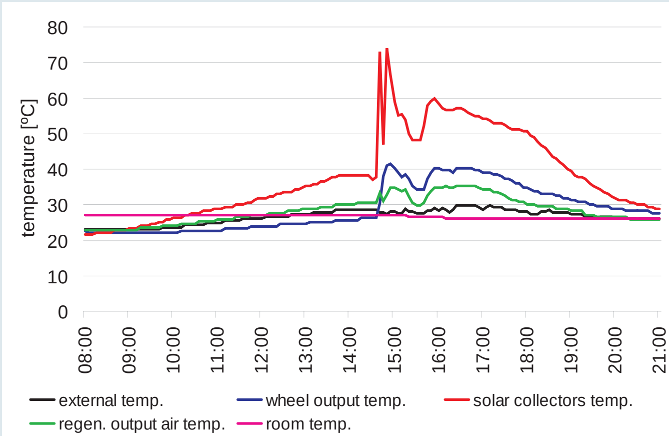


Figure 14: Measured data from the installed desiccant rotor in Mataró (source: Aiguaso/ Enginyeria)

Processes with liquid sorbent materials

Open desiccant air conditioning systems with liquid sorbent materials work according to the same principle as all open processes: outside air is dehumidified by means of sorption and cooled by water evaporation.

Figure 15 shows a system optimised for solar operation. Outside air is dehumidified in the absorber, where cooled contact surfaces are humidified with a concentrated liquid sorbent material using the falling film technique. The sorption heat is transferred to the exhaust air through a composite circuit system and an indirect evaporation cooler so that the outside air is dehumidified and cooled at the same time. A downstream cooler cools the dry air to below room temperature.

The sorbent material is diluted during dehumidification of the air. In an air-flow regenerator it is heated up to 60 - 80°C and re-concentrated. Heat recovery from the air and the sorbent material increases the efficiency and saves collector area.

Energy can be stored by storing diluted and concentrated sorbent separately. When using the usual aqueous lithium chloride solution as a sorbent, it is possible to achieve an energy storage density of up to 280 kWh/m^2 by using a special internally cooled absorber without diminishing the dehumidification potential of the concentrated solution.

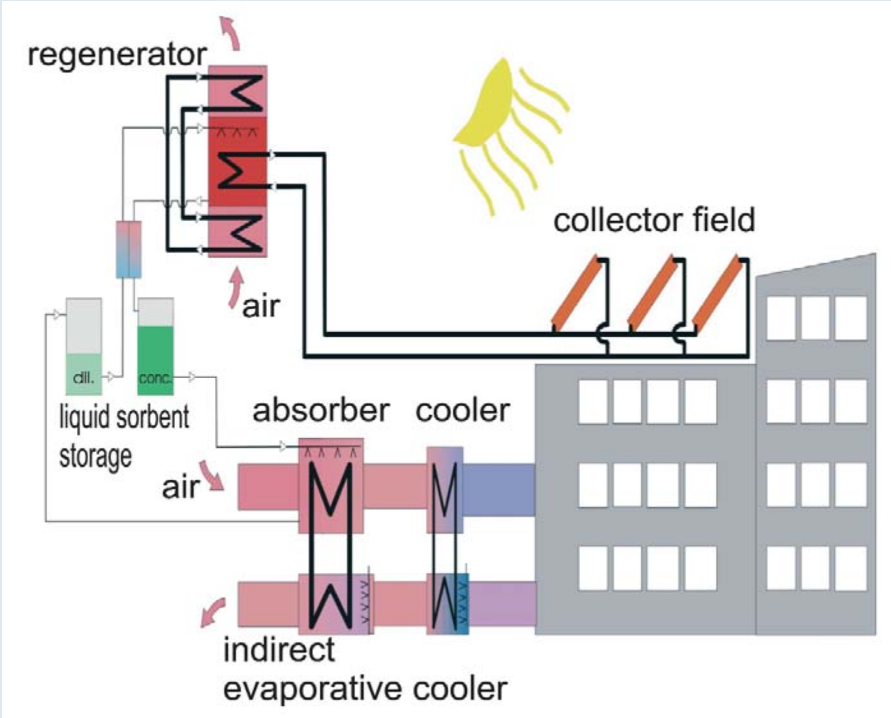


Figure 15:
Working principle of a system with liquid sorption and solar regeneration (source: ZAE Bayern)

Processes with liquid sorbent materials

Figure 16: 20 kW liquid desiccant system, Energy Engineering Research Center Building, Haifa. (source: G. Grossman, Technion Haifa/Israel)

Desiccant cooling systems with liquid sorbent materials are more complex than systems with rotors and are not yet available on the market. Some fundamental advantages such as potentially higher overall efficiency due to greater potential of heat and refrigeration recovery, lower possible regeneration temperature with the same dehumidification potential due to cooling of the sorption process, and the potential of efficient energy storage and, not least, the physical separation of supply and exhaust air flows could help establish them in combination with solar systems.

Planning, costs, integration

Energy balance, primary energy savings

The main aim of exploiting solar energy is to save primary energy. Any energy consumption balance for solar assisted air conditioning systems must take all energy flows into account in order to provide a realistic picture. This includes the energy for all pumps, e.g. in the solar circuit and in the return flow circuit, the electrical energy driving the fan in the cooling tower, and the energy used to provide refrigeration when insufficient solar heat is available.

There are two fundamental options: a second heat source may be used, e.g. a gas boiler to drive the thermally powered refrigeration process, or a second chiller may be installed that is driven by electricity. Figure 17 presents a basic overview of the primary energy consumption for a method of the first kind - solar collectors and a second heat source powered by fossil fuels as a backup. This analysis only includes the coefficients of performance of the refrigeration processes under comparison, along with the primary energy to electrical energy conversion factor.

The analysis shows the primary energy required per kWh refrigeration as a function of the percentage of solar coverage for various COP values of the thermally driven refrigeration process. The primary energy efficiency for generation of electricity was set at 0.36 kWh electricity per kWh of primary energy and for the fossil energy source 0.9 kWh of primary energy per kWh of useful heat. In the marked range, the diagram also shows the typical consumption of primary energy of conventional systems that are driven exclusively by electricity, with the lower curve for modern, efficient systems with a COP of 4.5 and the upper curve for old systems, for example, with a COP of 2.5.

The diagram in Figure 17 indicates that all methods described here, if operated exclusively with primary energy (e.g. natural gas), are less efficient than conventional cooling with modern compression chillers (COP 4.5). Depending on the system being compared and the thermal refrigeration technology in use, in thermally driven processes the solar system must deliver between 10 % and 55 % of the driving heat in order to achieve a break-even in terms of primary energy. Savings on primary energy are only possible if the percentage of solar coverage is even higher.

The diagram only provides a general basis as it neither accounts for part load behaviour nor the solar coverage of other heat consumers. It highlights the general problem, however, and illustrates that a detailed energy balance is significant in the design-phase to planning a system.

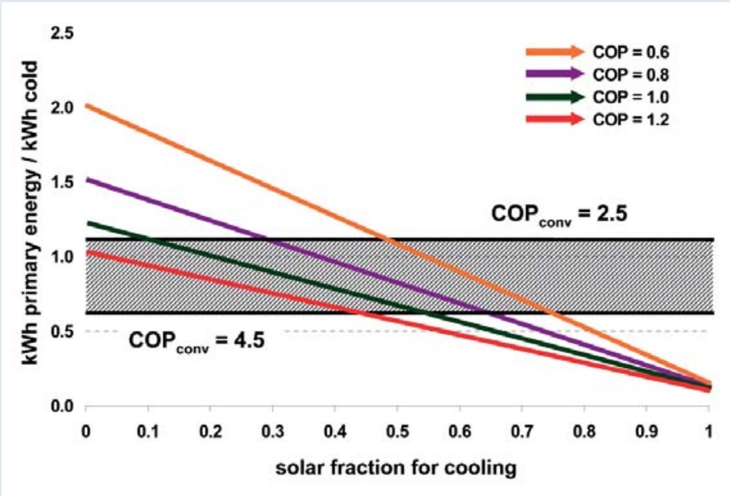


Figure 17: Primary energy balance of solar assisted air conditioning with fossil heat source as a backup (source: Fraunhofer ISE/Freiburg)

Key planning guidelines, integration with technical building systems

We can derive several basic guidelines concerning system design from the above energy balance:

- Solar cooling processes with a low COP and fossil fuel backup require a high percentage of solar coverage.

- A low percentage of solar coverage is sufficient for thermally driven refrigeration processes with a high COP.

- An alternative is to use a conventional refrigeration system (compression chillers) as a backup; this is generally acceptable for systems with a high installed capacity.

- Savings on primary energy are possible when using autonomous solar-thermal systems; in this case, however, it is not possible to guarantee adherence to prescribed indoor air conditions.

- In any case, the level of utilisation of the solar system should be maximised by incorporating other thermal consumers (heating, domestic hot water).

In practice it has evolved that many systems fail to achieve possible energy savings. The reasons for this are too complex hydraulic layouts and often insufficient control. With regard to design and operation, it follows that:

- The hydraulic system should be as simple as possible and as complex as necessary.

- The efficiency and capacity of both solar systems and thermal refrigeration or air conditioning processes depend on the operating temperatures. Demand-based control both of driving temperature, refrigerant temperature and recooling temperature can significantly increase overall efficiency. But this requires a complex control system that should only be implemented after thorough testing.

- A rigorous commissioning phase with subsequent recording and analysis of operating data is essential in order to achieve the targeted energy savings.

Planning aids: Task 25 design tool

The lack of suitable planning aids has proved to be a major obstacle to installing solar assisted air conditioning systems. A number of tools have thus been developed in various public-funded projects.

In Task 25 ILK Dresden headed a team that developed a simulation program covering the complete process of design and decision-making for solar air conditioning. One premise in developing the program was above all a detailed calculation of the capacity of solar energy supply.

In the course of simulating the overall system on an hourly basis, the system involves a calculation of the demand of the refrigeration and air conditioning systems (forward calculation) and then a calculation based on the yields of the solar energy supply and the benchmarks of selected system components (backward calculation) in order to determine the real outputs and exit states of the components. This helps identify any incorrect dimensioning of components and allows the user to estimate the effect of intentional undersizing, at the same time accepting a certain temporary deviation from the specified supply air conditions.

Since it is hardly possible to make any verifiable statements regarding the components in use during the early phase of decision-making, the inputs were reduced to a minimum and to the information available at this stage.

While the refrigeration machine can be chosen directly, a product-independent description based on transfer characteristics was used for the other components.

The simulated system consists of the solar system with collector, storage unit and backup system, refrigeration unit, air handling unit, and in-room components. Input variables for the simulation are the hourly climate data (weather data, e.g. test reference year) and the hourly energy requirements of the building (load file, see above).

The task of the simulation software is above all fast calculation of useful layout variations in order to determine the ideal solution for the specific application.

The results of the calculation provide information regarding the following energy related variables:

- electrical energy consumption of fans and compressors
- energy requirement of the backup system
- cooling tower water consumption
- water consumption when using well water
- humidifier water consumption

The software is marketed by ILK Dresden. After rigorous testing under Task 25, it will be available to interested users at the end of 2004. ■

Economic efficiency

Solar assisted air conditioning systems require more technical apparatus than conventional systems. On the one hand, they additionally require the entire thermal solar system; on the other hand, the recooling system is larger in thermally driven chillers as the COP of thermal methods is lower than the COP of electrically driven compression systems, which means that the amount of heat to be removed is greater.

Also, the specific costs of thermally driven chillers in terms of refrigeration are greater than the costs of conventional systems. All these factors mean greater costs of investment for solar cooling. On the other hand, the energy savings cut operating costs. This becomes particularly noticeable when the maximum electricity used by conventionally cooled buildings is due to their refrigeration/air conditioning systems. In this case, using thermally driven methods – depending on the current power price – can result in significant cuts in operating costs. Although exact statements regarding the economic efficiency of a solar cooling system always depend on the specific case in question, today the annual costs – i.e. the total costs including capital costs, operating costs, maintenance costs, etc. - of solar thermal methods are usually higher than the costs of conventional technologies.

In order to be able to dimension a solar system for a real solar cooling project under given conditions, a variable was efined in Task 25 Solar Assisted Air Conditioning of Buildings (see /Henning 2003/), which is designed to evaluate the combined energy-economic performance of a system, i.e. the costs of the primary energy saved, $C_{\text{Primary energy}}$; the variable is defined thus:

Figure 18 presents this variable as a function of collector area and storage unit volume for the hotel in Spain. We see a distinct minimum for the system layout of 140 m^2 collector area and a volume of the hot water storage unit of 90 m^3; this layout saves 36 % on primary energy compared to the comparable system.

$$C_{\text{Primary energy}} = \frac{\text{Annual costs of solar system} - \text{Annual costs of reference system}}{\text{Primary energy consumption of reference system} - \text{Primary energy consumption of solar system}} \quad [\Leftrightarrow/\text{kWh}]$$

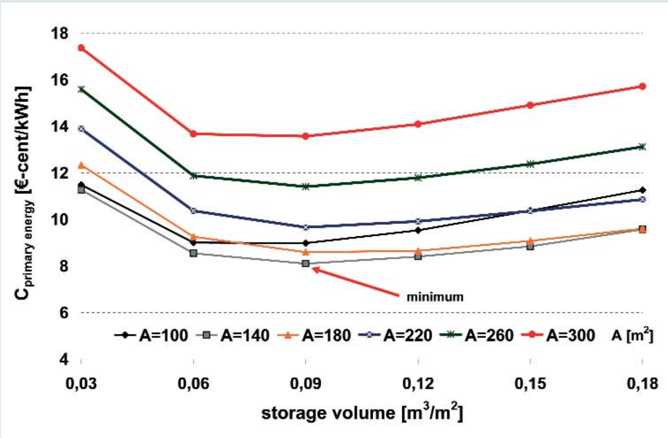


Figure 18: Costs of primary energy saved as a function of collector and storage unit size for the hotel in Spain (source: Fraunhofer ISE/Freiburg)

Summary

Components are already available that allow us to use thermal solar energy for air-conditioning buildings – albeit only for central systems, as are commonly used in the non-housing sector. But the technology is still in its infancy.

So far, only relatively few solar assisted air conditioning systems have actually been built. Experience with these systems shows that there are shortcomings particularly with regard to the hydraulic layout and control technology.
There are no standardised, fully developed system concepts, and it will require further projects with in-depth evaluation to achieve reliable, sturdy and energy-efficient component layouts and suitable control technology.

In this respect, the focus of future development is on system technology. But we can also expect to see considerable innovations with regard to component development in future. For example, small thermally driven chillers with outputs below 20 kW – both on the basis of absorption and adsorption technology – will come onto the market in the next few years; these systems will open up the way for totally new applications.

An interesting option for systems with greater capacity may be high-efficiency chillers, e.g. double-effect absorption systems or steam jet refrigeration systems in combination with high-efficiency collectors – vacuum tube collectors or single-axis tracking parabolic trough systems.

With regard to open sorption methods, the development of cooled sorption processes in particular will lead to relevant enhancements in terms of efficiency. Combined with reliable, easy to handle planning tools, as will be available shortly, all the aforementioned developments – in system technology and components – will result in a significant spread of solar cooling applications.

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TASK 25

Solar Assisted Air Conditioning of Buildings